ANALYSIS OF COUPLED OSCILLATORS APPLIED TO ANTENNA ARRAYS

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Abstract – **In recent years microwave oscillators are widely studied. They are used to guide the radiation pattern of a phased array antenna in a certain direction instead of the traditional beam steering methods. These new control methods use the injection-locking phenomenon [1]. An array of coupled oscillators produces output signals with a certain phase distribution that steer the beam in a particular direction. Directing the beam with an angle θ requires a constant phase progression between the adjacent oscillators [4]. Theoretically, we can change the free-running frequencies of the two outer oscillators of the network to get a phase progression range between -90° and 90°. This paper analyses two coupled oscillators through a resistive network. At first, their structures as well as their frequencies are identical. Then the frequencies are gradually changed in order to see the system's ability to lock to a common frequency. Oscillators were analyzed using both PSpice and ADS (Advanced Design System) and we were able to obtain a desired phase-shift, but the maximum valued we reached for this phase shift was approximately 65°. Above these values, the oscillators are no longer capable to synchronize. The reliability of our results was tested both with Spice and ADS. Future work will be focused on increasing the values for the phase shift, which results in frequency locking.**

Keywords: *oscillator, phase shift, antenna array, synchronization.*

1. INTRODUCTION

Oscillators are a fundamental component in RF and microwave systems. They are the core of all communication systems [5]. In this paper a network of coupled oscillators was studied in order to control an antenna array. A very important property of a phased array antenna is that the radiation direction can be controlled. The amplitude and phase of the signal injected into each of these antennas can be commanded so that it can control the shape of the radiation pattern of the network as well as its orientation [2]. We used the synchronization properties of the oscillators. Elementary oscillators must be able to synchronize stably at a common frequency and the phase shift must have a constant value. The synchronization it's accomplished only by coupling the oscillators (injection-locking phenomenon) [1]. Instead, the phase shift control and ensure the appropriate value cannot be easily accomplished. The mathematical model used is the Van der Pol model which is the equivalent of the entire oscillator. Coupled oscillators were analyzed using both Pspice and ADS and the phase shift was determined.

2. VAN DER POL OSCILLATORS

Oscillator is an electronic device who uses direct current power and generates a time varying signal. The difficult part in analyzing these devices is their inherent nonlinearity. The circuit must necessary include at least one non linear element in order to adjust and maintain the oscillation. Otherwise the steady-state would not be reached. The Van der Pol contains the necessary and sufficient elements to describe an oscillator. This model provides satisfactory results for many applications. Also the simplicity of the equations is very helpful [3]. The second order non linear differential equations that describe the oscillator behavior have the following form:

$$\ddot{x} + \varepsilon\,(x^2 - 1)\,\dot{x} + x = 0 \qquad (1)$$

where:

- ε is a control parameter that measures the degree of nonlinearity of the system;
- x is the dynamical variable;

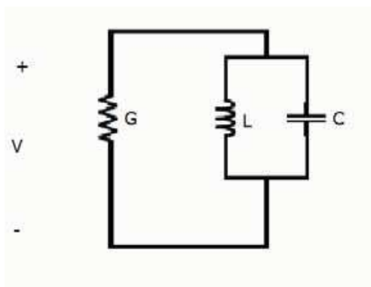

Figure 1: Structure of a Van der Pol oscillator.

The model consists of a non-linear conductance and a resonator as it can be observed in Figure 1.

The general expression of nonlinear conductance of the Van der Pol model is written as follows:

$$G = -\alpha + \gamma V^2 \tag{2}$$

where:

- $-\alpha$ - is the negative conductance necessary to start the oscillation;
- γV^2 - is the nonlinear conductance which modeless the saturation phenomenon

2. SPICE ANALYSIS

The simulated circuit is represented in figure 2. First the two oscillators are considered identical; the parameters values are the same as well as their free-running frequencies.

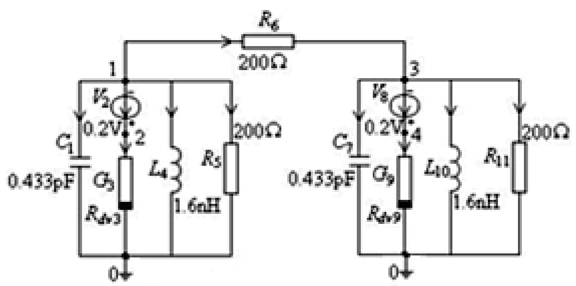

Figure 2: Two parallel resonant circuits coupled through resistive networks.

The two nonlinear resistors are also identical, and their characteristics are approximated by piecewise linear continuous curves as in figure 3.

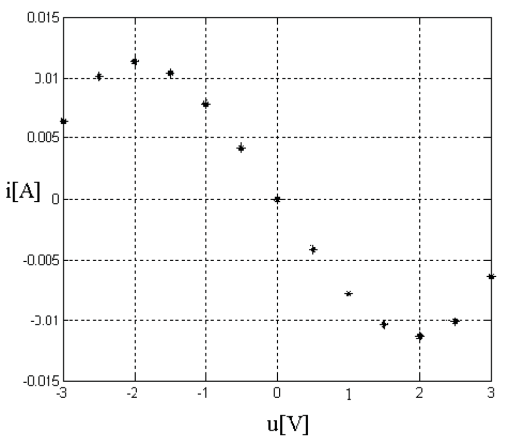

Figure 3: Piecewise linear approximation of the nonlinear resistors characteristics.

Our purpose is to couple the two oscillators with resistive networks as in figure 2. Oscillator 1 and oscillator 2 have the following frequencies:

$$f_1 = f_0\,(1+\alpha) \tag{3}$$

$$f_2 = f_0\,(1+\alpha) \tag{4}$$

where f_0 is the center frequency and α is a percentage

The coupling circuit is made of a resistor R_C which is equal to 200Ω.

For α = 0%, the frequencies for both oscillators are f1 = f2 = 6.03 GHz, and the capacitors values are C1 = C2 = 0.433 pF.

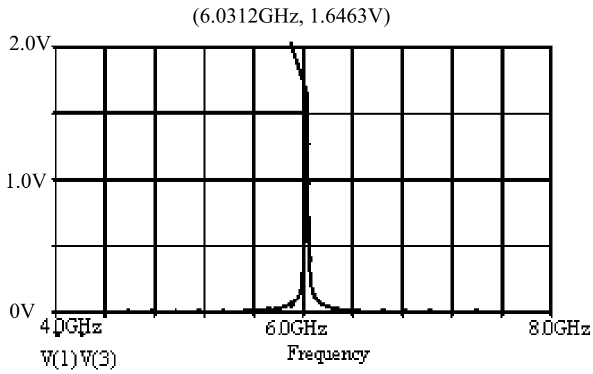

Figure 4: Synchronization frequency.

The simulation has lead to two sinusoidal waves with the same phase shift.

Now, in order to show the ability of this system to achieve the desired phase shift, we are changing the free-running oscillation frequency of the two oscillators, f1 and f2. For α = 4%, the synchronization frequency is f= 5.941GHz and the phase shift between output voltages is φ=14.97°.

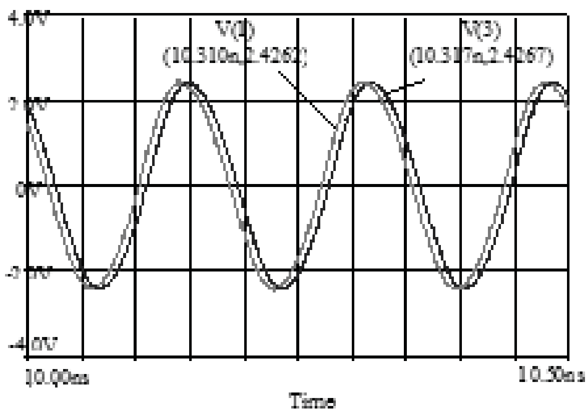

Figure 5: Output voltages for α = 4%.

The maximum value of the phase shift is reached for a percentage of *14 %* since, above this value, the two oscillators are not able to synchronize anymore.

The phase shift corresponding to this value is φ=65.07° and the synchronization frequency f=5.831GHz (Figure 6 and Figure 7)

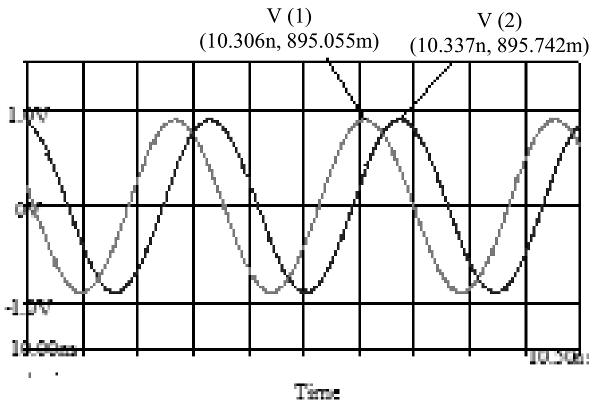

Figure 6: Waveforms for the output voltages for a 14% percentage.

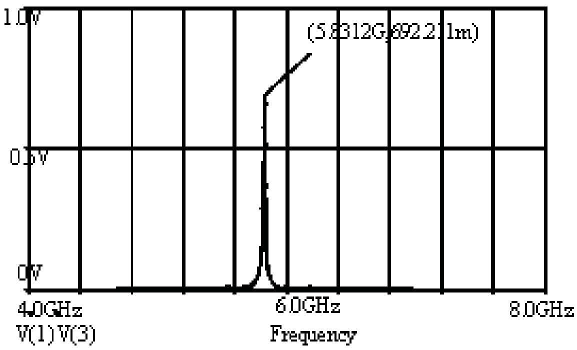

Figure 7: Synchronization frequency.

3. ADS ANALYSIS

In this section the coupled system was analyzed with Advanced Design System software in order to validate our results.

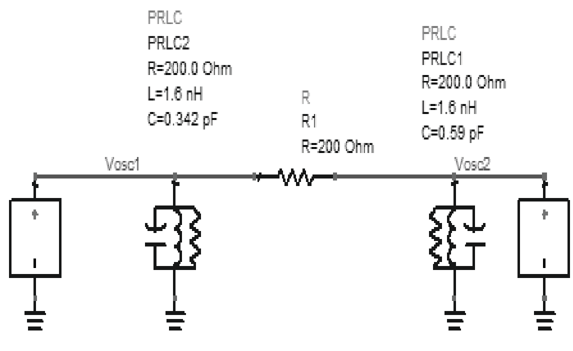

Figure 8: Two coupled oscillators.

First we simulated the two identical oscillators having the same structure, the same values for the parameters and the same free-running frequencies. When α is zero the frequencies have equal values f1 = f2 = 6.022 GHz and the same phase shift.

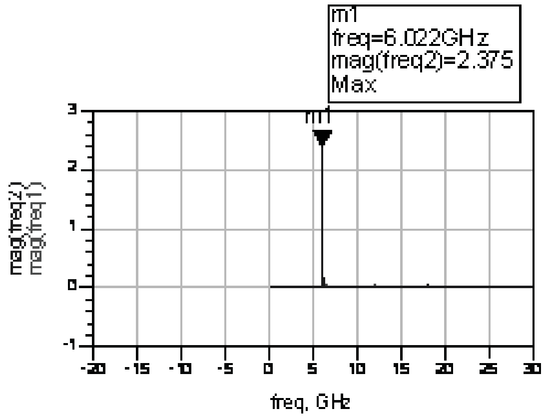

Figure 9: Synchronization frequency for α = 0%.

Now, we modify the free-running frequencies for each oscillator by changing the capacitor values. At a 4% value of α, the synchronization frequency is 5.920GHz and the waveforms for the output voltages can be seen in figure 10.

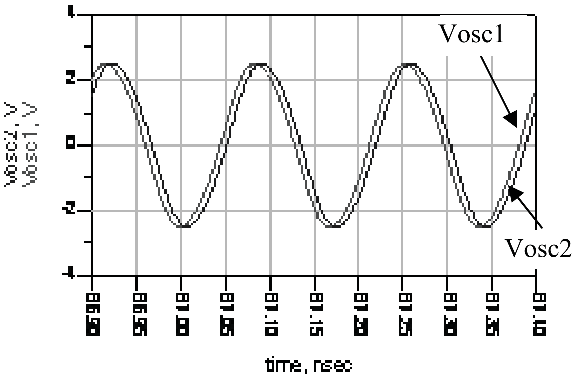

Figure 10: Waveforms of the output voltages for α equal to 4%.

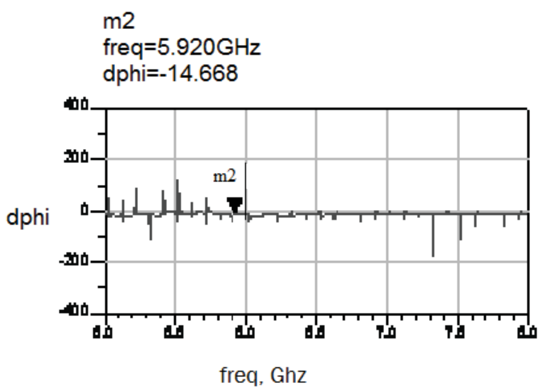

Figure 11: The phase shift for α=4%

The resulting phase shift is comparable to that obtained previously φ=14.668°.
Finally, the maximum phase shift obtained with ADS is for α = 14%. If we increase this value the oscillators are not able to synchronize anymore.
The value for the phase shift is 62.165, as shown in the following figure.

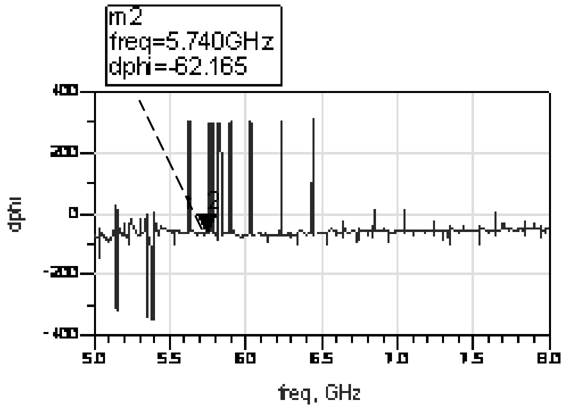

Figure 12: The maximum phase shift.

The synchronization frequency is f=5.740GHz, with a slightly different variation of the previous one.

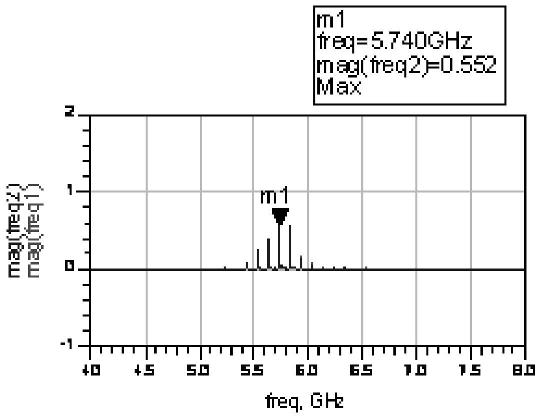

Figure 13: Synchronization frequencies.

4. CONCLUSIONS

The new developed technologies demand high performances, low manufacturing cost and reduced occupied space. Antenna array systems are among these technologies and their performances can be greatly improved. The way oscillators work and the phase shift are very important in orienting the radiation pattern, in a phased antenna array, in a certain direction. Research is made so that a particular phase shift can be obtained by choosing the free-running frequencies of the oscillators in the array. But a big problem with autonomous circuits is the limited control over the characteristics solution. This lack of control is caused by the specific nonlinearities of this type of circuits. In this paper, we have analyzed a network of coupled Van der Pol oscillators, used to control an antenna array.

At first, we tried to couple the two Van der Pol oscillators at a frequency equal to 6.00 GHz. Then, we changed the free-running frequencies of each oscillator, using the following formulas $f_1 = f_0(1+\alpha)$ and $f_2 = f_0(1-\alpha)$, where f_0 is the centre frequency, equal to 6.00 GHz, and α is a percentage of f_0. The maximum phase shift that we obtained is approximately φ = 65.0˚ for α = 14.0%. Above this value of α, the oscillators are not able to synchronize.

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